

B. Alloying Element Vaporization during Laser Spot Welding of 304 Stainless Steel

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Introduction

Laser spot welding is characterized by small weld pool size, high temperature and very short duration of the process. The temperature in the weld pool can be very high often exceeding the boiling point of the alloys. Because of the high temperatures selective vaporization of volatile alloying elements takes place from the weld pool surface. In extreme case, tiny liquid metal particles can be expelled from the weld pool surface due to a large recoil force exerted by escaping vapor. As a result, the composition of the solidified weld pool often differs significantly from that of the alloy being welded. The loss of alloying elements affects weldment properties. The goal of this investigation was to validate the model to calculate temperature field and vaporization rate of alloying elements and the resulting composition change of 304 stainless steel.

Technical Approach

The experiments were performed at the Sandia National Laboratories. A pulsed Nd:YAG laser was used for laser spot welding with varying pulse energies from 1 to 5.5 J, and pulse durations of 3.0 and 4.0 ms. The weld pool geometry, vapor composition, mass loss and composition change of weld pool were determined by both experiments and computation, and these two results were compared to validate the model. The temperature fields were calculated by a three-dimensional heat transfer and fluid flow model. The temperature data obtained will be used for calculation of vaporization. A model for the calculation of evaporation rate and composition change was developed based on principles of transport phenomena, kinetics, and thermodynamics. Vaporization rate of alloying elements is driven by both total pressure and concentration gradients. The rate of evaporation and condensation were both considered in the calculations.

Results and Discussion

The transient heat transfer and fluid flow model was validated by comparing the experimental and calculated results of weld pool geometry and temperature fields under different spot welding conditions. The ratio of the heat transported by convection and conduction, i.e., the Peclet number for heat transfer increased with power density and the duration of the laser pulse. The peak temperature and velocities increased significantly with the deposited power.

Computed temperatures at the weld pool surface were found to be higher than the boiling point of 304 stainless steel depending on welding conditions. As a result, evaporation of alloying elements took place, which was driven by both the pressure and concentration gradients. Iron, manganese and nickel were the dominant species in the vapor phase. During the heating cycle, the evaporation rate increased significantly with time as the pulse progressed. At the end of the pulse, the evaporation rate drops almost instantaneously to a very low value due to rapid cooling of the weld pool. The loss of alloying elements becomes more pronounced with the increase in laser power density. This behavior is consistent with higher temperatures at higher laser power densities. The vapor composition and composition change of weld pool calculated from model agreed well with the experimental results. When the laser power density is high, the

computed mass loss were found to be much lower than that of the measured values because of the ejection of the tiny metal droplets owing to the recoil force exerted by the metal vapors, which has been verified by experiments and calculation.

Conclusions

The fusion zone geometry produced by the laser spot welding of 304 stainless steel could be predicted from the transient heat transfer and fluid flow model under various welding conditions. Loss of alloying elements from the weld pool during laser spot welding was investigated experimentally and theoretically. During the heating cycle, the evaporation rate increased significantly with time as the pulse progressed. The vapor composition and composition change of the weld pool calculated from model agreed well with the experimental results. The computed vapor loss was found to be lower than the measured mass loss because of the ejection of the tiny metal droplets owing to the recoil force exerted by the metal vapors. The ejection of metal droplets was predicted by computations and verified by experiments.